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CANMET
Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

ANNUAL REPORT OF THE ACTIVITIES OF THE CANADIAN COMBUSTION RESEARCH LABORATORY FOR THE YEAR 1981

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ENERGY RESEARCH PROGRAM
ENERGY RESEARCH LABORATORIES
REPORT ERP/ERL 82-17(TR)

HIGHLIGHTS

The R & D effort of the Canadian Combustion Research Laboratory is heavily oriented toward the conservation of liquid fuels and the expanded use of low-quality fuel in industry. It reflects both departmental goals to achieve national energy security and industrial requirements for innovative technology to efficiently burn a wide range of fuels with minimal environmental impact. During the year all on-going activities, which incorporate a complementary mix of extramural contracts, shared-cost work and in-house projects, were expanded and evaluated under the recently implemented provisions of the National Energy Program.

Priority projects in which significant progress was made included: the development of design criteria for chimneyless, ultra-high efficiency gas furnaces for home heating; the demonstration of fluidized-bed technology for energy from low-grade coal; the feasibility of coal/liquid mixtures as a substitute fuel in industrial furnaces designed for oil; and the elucidation of mechanisms for reducing NO_x formation in pulverized-coal-fired utility boilers. In addition, work was completed on the flame and combustion characteristics of raw bitumen contaminated with water and dirt, low-volatile inert coals from newly-opened mines in the vast northeastern British Columbia coal development and various particle sizes of wood waste with various moisture levels. Combustion scientists also served as scientific authorities on research contracts involving CANMET, the International Energy Agency, the Canadian Electrical Association, the ENFOR program, the National Research Council and the Ministry of Transport.

During 1981, the Canadian Combustion Research Laboratory staff published 17 papers, prepared 22 internal or confidential reports, made presentations at 17 seminars or symposia and participated as members of 19 technical or scientific committees as well as being the scientific authority on 20 contracts or research agreements, with a total value exceeding $1.5 million.

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CONSERVATION TECHNOLOGY

Oil and Gas Utilization (410100)
Residential Space Heating and Industrial Processes (410101)

Domestic Heating

The Canadian Combustion Research Laboratory (CCRL) has conducted detailed research on domestic heating systems for the past eleven years, on a continuing basis. Fully equipped laboratory facilities allow measurement of efficiency and emissions parameters on a cyclic basis, for both current equipment and prototype designs. In addition, a number of homes in the Ottawa area have been instrumented to allow monitoring of the heating system performance in actual use in order to determine seasonal performance.

Oil-Fired Heating System

In evaluating oil-fired systems, the most effective technique for improving performance was found to be the replacement of the existing oil burner mixing head with a flame retention head. This approach, which allowed significant reductions in excess air and flue gas temperature, gave efficiency gains of 12% to 18% in laboratory tests, and similar or greater fuel savings in the field, while offering a straightforward change of a minimal number of components on the existing burner.

With this new head, firing rate reductions of over 25% are possible without loss of control of combustion air or fuel/air mixing. Downsizing of the heating system in this fashion, to make the furnace output more compatible with the heat demand of the dwelling can result in additional fuel savings of 5% to 10%.

A national survey of the performance of existing equipment was carried out in 14 Canadian cities, yielding data on 15,000 homes. Steady state efficiencies were determined using CO_2 and stack temperature readings. Draft and smoke number were also measured and recorded, along with the make and model of furnace and burner, fuel and electrical consumption records, house characteristics and demographic data. Summary results are presented in Table 1. The average excess air was 100%, corresponding to a CO_2 level of 7.5%, with a steady state efficiency of 74.5%. This indicates good potential for improved performance with retrofit flame retention heads.

Table 1 - Canadian domestic oil furnace/boiler survey

City	Number in Sample	Carbon Dioxide %	Steady State Efficiency %
Vancouver, B.C.	495	7.1	71.3
Nanaimo, B.C.	1898	6.8	72.8
Thunder Bay, Ont.	258	6.6	74.4
Sault Ste Marie, Ont.	454	7.5	74.9
Timmins, Ont.	552	7.5	76.9
Toronto, Ont.	760	6.8	71.7
Ottawa, Ont.	770	7.9	75.4
Campbells Bay, Que.	228	8.1	75.4
Montreal, Que.	876	8.5	71.6
Drummondville, Que.	867	8.5	77.8
Quebec, Que.	2967	8.2	76.1
Chicoutimi	1068	8.0	75.5
St. John, N.B.	1399	6.6	72.5
Moncton, N.B.	2501	7.7	75.2

Gas-Fired Heating System

Conventional gas-fired heating systems operate at a low seasonal efficiency, between 55 and 60%, well below their steady state efficiency. Changes in technology could offer significant reductions in fuel consumption by improving combustion performance, reducing off-cycle losses, eliminating the need for downstream infiltration through the draft hood and increasing the steady state efficiency, to the point of condensing some of the water vapour present in the flue gas and regaining the latent heat.

In particular, because of its high hydrogen content, relative to No. 2 oil, natural gas tends to suffer an efficiency penalty because of its high hydrogen loss, made up of the latent heat loss and the portion of the sensible heat carried by the water vapour. Having this high hydrogen content has also lead to the possibility of localized condensation at cold spots within the conventional heat exchanger, and the likelihood of corrosion therein.

With the gaseous fuels, natural gas and commercial propane, having very low levels of sulphur along with high levels of moisture in their flue gases, it has become attractive to designers and manufacturers to overcome the limiting effects on efficiency with gas by making a determined effort to actually condense this vapour and regain much of the heat within a heat exchanger specifically designed for that purpose.

An additional loss which can be significant is that due to the dilution air. This is heated house air which is entrained with the flue gas through the draft hood of a conventional gas furnace, downstream of the heat exchanger. For most installations, this air represents a major loss of warm air up the chimney while the furnace is operating. From Reference 2, the average dilution level is about 389%. This represents 5-7% in terms of the heating load over a typical Ottawa heating season of 4763 Degree Days. It is the major air demand of the heating system, and can represent a supply problem in a tight house.

CCRL is conducting a research program in domestic gas-fired heating systems to help develop some of the most promising of the new technologies and to determine their performance, both in the laboratory under controlled conditions and in the field, under real-life conditions. Under this program the performance of a number of condensing furnaces, either in the prototype stage or actually on the market are being examined in detail, with the goals of improving the performance of the present units and making design modifications or developments for new units.

Another problem that the tight house creates is related to other air evacuating equipment, such as kitchen or bathroom fans, clothes dryers and "roaring" fireplaces. These can create prior demands on air related to most naturally aspirating gas-fired units. If the house is too tight, the easiest place to get air is down the chimney of the gas furnace. This disrupts combustion and can result in large amounts of carbon monoxide being released into the dwelling, with potentially catastrophic results.

Another loss in gas-fired heating systems is due to the condensate which is merely the sensible energy in the condensate going down the drain; it is dependent on the amount of condensate and its temperature.

Description of Condensing Furnaces/Boilers

Four different types of condensing warm air furnaces and one type of condensing boiler were examined. The types of furnaces were as follows: condensing heat exchanger to concentric oil-type furnace, two types of finned tubed condensing heat exchangers to gas clamshell furnaces, and one stainless steel condensing clamshell to a conventional clamshell, denoted by units B, C and F, respectively. The boiler, unit E, was the pulsating combustion type, similar in concept to one developed in Canada and tested by CCRL in 1965.

All of the warm air furnaces used an induced draft fan, downstream of the condensing heat exchanger, to evacuate the combustion products, which are then taken through the PVC pipe to the side wall of the house. Condensate is collected from the bottom of the stainless steel heat exchanger, as well as from a trap downstream of the fan and sent either directly to a drain or, if required by local regulations, neutralized in a holding tank before removal. This concept can effectively eliminate the potential for flow reversal under poor draft, such as was described in the previous section.

Retrofit Condensing Furnaces

Recognizing that most of the existing gas-fired furnaces in Canada operate at a relatively low efficiency over the heating season, on the order of 55% to 60%, CCRL is carrying out a major program to develop equipment which could be used to upgrade three existing furnaces to the very high levels potentially available with the new advanced performance equipment now entering or about to enter the marketplace.

In particular, one of the retrofit packages, produced under contract to CCRL by a major furnace manufacturer, is designed to convert a conventional gas furnace into a condensing unit. The technique is similar to the condensing furnaces previously described, whereby there is a conventional front end furnace, to date fired only with naturally aspirating burners, and a second add-on portion with a stainless steel heat exchanger and induced draft fan (Fig.1). The draft hood can either remain or, preferably, can be sealed up. Units A and D are prototype retrofit systems when connected to conventional gas furnaces G and H and fired with propane and natural gas, respectively.

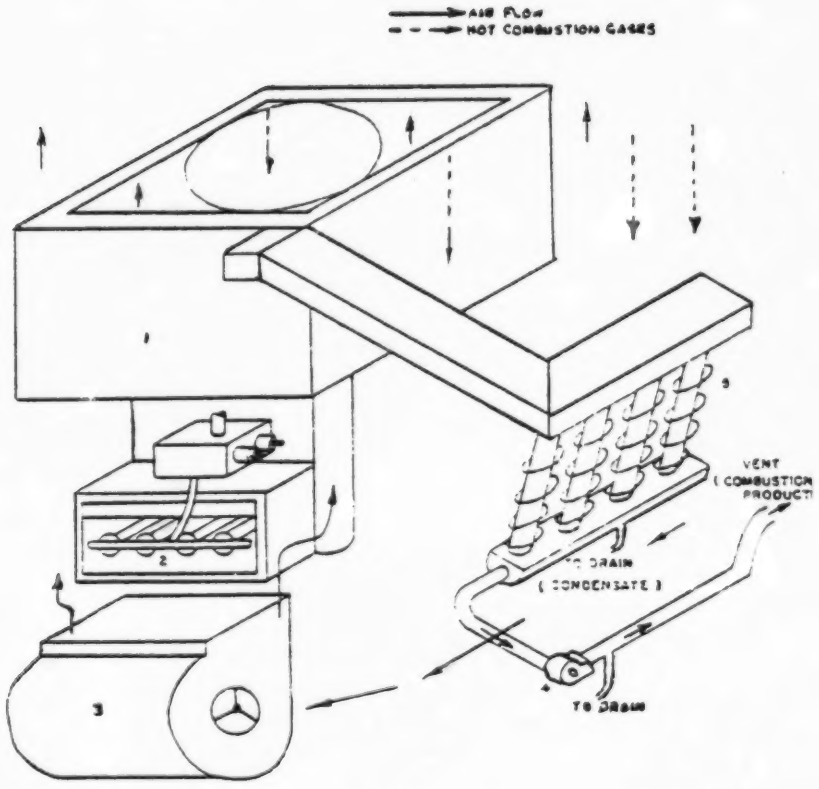

Fig. 1 - Condensing furnace with stainless steel finned tube heat exchanger

Field Measurements

In the field, flip-flop trials are being conducted over the heating season, with a conventional gas or electric furnace as the baseline. Depending on the character of the heating period, each furnace runs for one or two weeks at a time, then the other unit is operating, and so on so that a good distribution of performance data is obtained over the whole range of the heating season. The furnaces are instrumented to provide specific gas or electricity consumption, time of operation and number of cycles, along with at least hourly measurements of ambient conditions.

A pulsating combustion boiler and a condensing furnace are being tested in occupied homes of conventional construction, as part of a contract to determine the performance of a number of advanced technology gas-fired appliances, to Consumer's Gas by CCRL. A different condensing furnace is installed in an unoccupied, fully instrumented, high efficiency house, built for detailed energy analysis in companion with three other similar units. This second trial is being carried out in cooperation with HUDAC, Consumer's Gas and the National Research Council of Canada.

Due to problems with delivery of equipment, data is only available for the trial comparing the condensing boiler with a conventional unit. The steady state efficiencies were 88.9% and 77.0%. Average consumptions per degree day were 18.5 kBtu and 27.8 kBtu, respectively. On the basis of preliminary data, the condensing boiler showed a 33% fuel saving over the heating season.

More detailed results on this installation, along with several other improved efficiency units, will be available at the end of the 1981-82 heating season.

Laboratory Experiments

Detailed experiments were performed on each furnace, at three conditions, to measure its performance. Each unit is operated for a continuous 3 hour run to obtain accurate steady state information. Then the cycling test as prescribed by the U.S. Department of Energy to measure a cycling (seasonal) efficiency, consisting of a long on-cycle to steady state, off for 20 minutes, on for 30 minutes, off for 40 minutes and on for 30 minutes. Finally, a series of 10 minute on 30 minute off cycles are run.

Tables 1 and 2 present a summary of the results obtained from steady state experiments on the various furnaces, firing propane and natural gas, respectively. For comparative purposes, data for two conventional furnaces, fired with the same fuels, was obtained.

The two propane furnaces behave similarly. While operating at a slightly higher excess air level, the retrofitted furnace, unit A, was able to achieve 1% better efficiency, probably because of slightly better heat transfer. The amount of condensate generated was up. However, both units actually produced very little condensate, 18% and 13% of that possible. Ph levels of the condensate was similar, about 3. Flue gas temperatures were 9°C and 18°C above the dewpoint. It is anticipated that better performance would be obtained when firing natural gas, where the dewpoint would be some 5°C higher.

Because of the low exit temperatures, very little sensible heat remains in the flue gas; the dry flue gas loss is low, less than 20% that of the standard furnace. Thus even though little condensation is achieved, efficiencies are still high, over 90% in both cases.

Comparing furnace C and boiler E, both units are operating at very low excess air levels. The boiler has the highest efficiency, primarily because of a low flue gas temperature. The dry flue gas loss for this unit is less than 1%. Furnace C has an exit temperature 26°C higher, so that its dry flue gas loss is doubled, although still low at 1.9%. Condensate levels are similar, with the boiler 6 percentage points higher.

Furnace D, the other retrofit unit, also has an exit temperature similarly above the dewpoint, even though the actual temperatures were lower due to the higher excess air levels. However, there was very little stratification in the tubes, so that there was not the localized condensation that occurred in unit C. Efficiency was slightly lower at 88.2%, and only 16% of the water was condensed.

Furnace F has the lowest efficiency, with effectively no condensation, even though it was the only warm air furnace with a flue gas temperature actually below the dewpoint. This unit has a single stainless clamshell as the condensing heat exchanger, so that there is no localized cooling. Its high excess air yields an efficiency of just below 86%.

Table 1 - Furnace performance at steady state, propane-fired

Furnace	Excess Air,%	Flue Gas Temp, °C	Dry Flue Gas Loss, %	Hydrogen Loss, %	Dewpoint °C	Efficiency %	Condensed %	pH
A	104	50.5	2.0	6.8	41	91.2	18	3.0
B	98	58.9	2.3	7.4	40	90.4	13	3.2
C	69	269	12.6	9.4	47	78.0	-	-

Table 2 - Furnace performance at steady state - natural gas-fired

Furnace	Excess Air,%	Flue Gas Temp, °C	Dry Flue Gas Loss, %	Hydrogen Loss, %	Dewpoint °C	Efficiency %	Condensed %	pH
C	12	78	1.9	7.6	57	89.5	24	3.8
D	163	62	3.1	8.6	40	88.2	16	2.9
E	21	52	0.9	7.0	55	91.9	30	5.7
F	111	49	3.8	10.3	50	85.9	3	4.0
G	52	191	7.8	11.2	53	81.0	-	-

NOTES

Plastic Condensing Heat Exchangers

One promising new development which has been produced under contract to CCRL is a condensing furnace which operates in a similar manner to the other Canadian furnaces previously described in that it is effectively an add-on to a conventional gas furnace. However, this unit is quite distinct in that it is using a plastic for the condensing heat exchanger, rather than the stainless steel that the other units utilize. The plastic is arranged in layers ressembling torsion boxes to build up a cross-flow heat exchanger. The other unique feature is a recirculation mechanism bringing a large portion of the flue gases back to the front of the condensing heat exchanger to control the inlet temperature to acceptable levels for the plastic. A schematic of the unit is shown in Figure 2. If the life of the plastic is satisfactory, this will be a major way that the cost of the condensing furnaces may be kept to reasonable levels.

A further contract has been let this year to optimize the system design and components, as well as to ensure compatibility of the materials to the potentially corrosive condensate. Three working prototypes will be produced for field evaluation over the next heating season.

Industrial Processes

Effect of Oil Atomization Parameters on Heat Transfer (FERA-Phase II)

This project was commissioned by the Combustion Sub-Committee of the Ferrous Energy Research Association (FERA) Technical Committee. The work was performed in the CCRL research tunnel furnace, using a dual-fuel, barrel-mix, burner, provided by FERA. The objective of the project was to evaluate the effect of varying steam/oil ratio and fuel oil temperatures on the heating efficiency of the steam-atomized oil flame while maintaining a constant burner emulsion pressure. Burner emulsion pressures were maintained at approximately 345 or 482 kPa by changing the burner tip size for each change in the steam-oil ratio. At the request of FERA raw data only was to be acquired and reported; accordingly no interpretation of the experimental results was provided, but additional atomization parameters were examined as part of the inhouse R & D program and these are currently being evaluated.

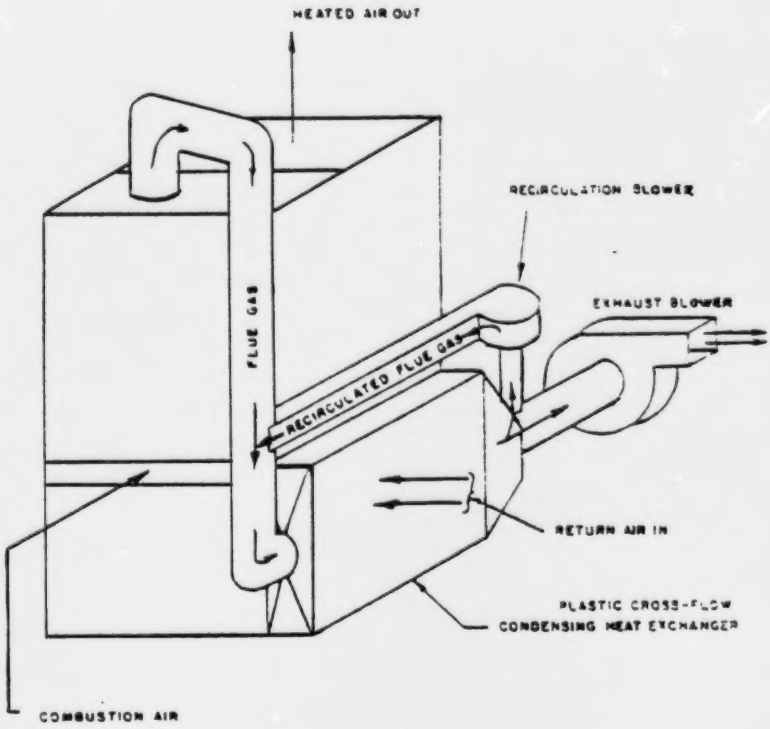

Fig. 2 - Prototype condensing furnace with plastic heat exchanger and recirculating flue gas

Assessment of Contaminated Emulsified Heavy Bitumen as a Boiler Fuel

This project was undertaken in collaboration with Union Oil (Canada) Ltd. and the Alberta Oil Sands Technology and Research Authority (AOSTRA). The major objective was to determine if sand and water contaminated bitumen, direct from the in situ extraction process, could be used as a boiler fuel and how much moisture must be removed for good flame stability and heat transfer.

The combustion trials are completed and the data is presently being interpreted and reported. Union Oil representatives witnessed the trials and observed the successful combustion of emulsions, containing up to 30% moisture in the CCRL flame research furnace. A bi-fluid, tip-mix burner was used. Air-atomizing produced stable flames with satisfactory combustion characteristics. Steam-atomizing produced lower quality flames, lower heat transfer rates and higher soot emissions than did air-atomized flames.

The following problem areas were noted:

(a) Emulsion temperatures in the day tank and fuel lines must be maintained above 85°C, for satisfactory pumping to the burner and all fuel lines should have provision for flushing with a distillate fuel oil.

(b) The emulsion supply system should have provisions for coarse filtering before the day tank and fine filtering before the pump, to remove grit and sand. An indicator to give advance warning of filter plugging is recommended.

(c) In-line heaters should be of the low-watt density, electrical type or a steam-type, to prevent coking of the heater elements and subsequent deterioration in heater capacity.

(d) Stable flames with good combustion requires a minimum fuel temperature of 120°C at the burner, with a high enough pressure at the burner to prevent flashing of water to steam at the burner tip. It was found that a pressure corresponding to 10°C below the saturation temperature eliminated flame instability and sputtering.

(e) Flame stability can be improved by a refractory quarl or the use of a continuous pilot-flame.

(f) Erosion of burner tips can be minimized by use of hardened material such as tungsten carbide, stellite or nitrided tool steel, or by choice of an appropriate burner for slurry fuels.

(g) Combustion efficiencies were generally over 99.9% for air atomizing.

(h) Optimum heat transfer and maximum NO emissions occurred between 10 and 20 wt % water in the emulsified bitumen.

Low-Calorific Gas Burner Development

The development and field testing of the low Btu gas burner has been completed, reported, and patent application initiated by CANMET. Industry enquiries on its use for wood gasifiers, B.F. gases, etc., are being referred to the contractors and developers, the Canadian Gas Research Institute. Novel features of this burner allow it to use hot, dirty gas from coal or wood gasifiers. Normally gases are cooled to remove tarry matter prior to burning, but this results in a significant loss of energy due to the removal of both sensible heat and the calorific value of the organic condensibles.

Road Vehicle Economy (410102)

Since 1973, CCRL has had a program to study the effects of Canadian climate on automobile fuel consumption, both with road trials and with dynamometer trials in temperature-controlled environments. The program has indicated that, for vehicles having engines with conventional technology, (i.e. simple carburation, and relying solely on an oxidation catalyst to meet emission regulations) fuel economy and emissions degrade rapidly with decreases in ambient temperatures. Those vehicles having engines with advanced combustion design, such as high speed diesels, stratified charge, lean burn or other computer-controlled systems to control combustion performance, degrade much less rapidly with respect to both fuel economy and emissions. These results have been reported to the Society of Automotive Engineers which this has resulted in a major manufacturer (Chrysler Canada) submitting a proposal to improve engine technology for Canadian winter conditions.

Under Phase I, which has just been completed, modifications include an early fuel evaporation configuration (EFE), an engine block heater conservation configuration with additional study on block heater performance and a high compression configuration with optimized spark control.

With the EFE, fuel economy was improved 20% over the first portion of the cycle (bag 1), and 6% overall at -20°C, relative to the 25°C baseline.

For the block heater conservation configuration, stabilization times were reduced 40%, relative to the base configuration, yielding fuel economy improvements of 8% on the city cycle and 9% on the highway cycle, relative to the 25°C baseline.

The optimum electric block heater preheat time was 2.5 hours; at -20°C, this gave a fuel economy benefit of 10% over the city cycle.

The high compression configuration, with a one number increase in compression ratio, decreased fuel consumption by 4% to 8% at all test temperatures.

COAL TECHNOLOGY

Combustion (430700)

Conventional Combustion

Canadian utilities and industry are rapidly converting from premium liquid fuels to indigenous coals in response to federal initiatives to achieve oil independence and energy security under the National Energy Program (NEP). In addition, Canadian coal companies are vigorously attempting to secure a reasonable share of the world market, often with newly developed thermal coals of unknown quality and performance. These activities have resulted in a collaborative government/industry combustion research program under the CANMET Minerals and Earth Sciences Research Program, Energy Technology Activity.

The objectives of the conventional coal combustion research group are as follows:

1. to develop new or improved techniques for efficiently utilizing pulverized coal and renewable fuels as a substitute for oil in industrial processes;
2. to define and optimize the combustion performance of low-grade coals from new mines or waste materials in pulverized-fired combustion systems;

3. to promote the development, and where feasible, the implementation of coal-liquid mixtures (CLM) as a substitute fuel for oil in existing oil-fired equipment and as an alternative to direct coal-firing in other combustion equipment;
4. to conserve and improve the use of fuel oil through operational and design modifications to industrial combustion systems;
5. to keep abreast of domestic and foreign combustion R & D and where appropriate to participate in joint R & D projects relevant to Canadian needs; and
6. to minimize the environmental effects of the increased use of coal in industrial and utility combustion systems.

With these objectives in mind the following projects and elements were undertaken in the 1981 FY.

Coals as a Substitue for Oil (430701)

The major objective of this project is to characterize the flame and heat transfer properties of raw, beneficiated and blended thermal coals and washery rejects for use as substitute fuels in industrial process kilns, currently fired with oil or gas.

Tent Mountain - Vicary Creek Coal Rejects

An experimental combustion and heat transfer study was undertaken to determine the feasibility of burning beneficiated washery rejects from the Coleman region of Alberta in mineral processing kilns. The beneficiated rejects were a reclaimed by-product of previous coal cleaning activities at the Tent Mountain and Vicary Creek seams. The project was undertaken in the CCRL pilot-scale tunnel furnace and was complimentary to previous work in the pilot-scale boiler.

The objectives of the research project were:

(a) to determine the aerodynamic requirements for a stable coal-flame condition;
(b) to evaluate the flame and heat transfer characteristics of the coal, under controlled aerodynamic and combustion conditions;

(c) to assess the gaseous and particulate matter emissions produced during combustion;
(d) to generate combustion efficiency charts for the coal; and
(e) to compare the combustion properties of this coal with those obtained from No. 6 fuel oil.

The conclusions of the study were:

1. The beneficiated Tent Mountain-Vicary Creek coal rejects produced an easily ignited, highly stable flame without the use of support fuel.
2. Flue gas emissions were normal for a typical coal fuel with the fly ash emissions and nitric oxide concentration higher and the sulphur dioxide concentration lower than when No. 6 fuel oil is burned. The latter is to be expected, due to the lower sulphur content of the coal rejects.
3. Overall axial heat transfer patterns indicate a more rapid release of heat from oil flames than from the coal flames, which are only slightly affected by swirl and excess air levels.
4. Combustion efficiencies of this coal were 99.6% compared to No. 6 fuel oil at >99.9% under the same operating conditions. Swirling the flame or increasing the excess air levels had no apparent effect on these efficiencies. Because of the much longer furnace residence times and higher volumetric heat release rates in full-scale equipment, combustion efficiencies close to 100% should be readily attainable in industrial process kilns.

Raw, Oxidized, Beneficiated and Blended Thermal Coals

Experimental combustion evaluations to establish the flame and heat transfer characteristics of several coals were undertaken in the CCRL pilot-scale tunnel furnace. The coals were:

(a) Line Creek oxidized thermal coal;
(b) Quintette coal;
(c) Sage Creek blended thermal coal;

(d) Shaughnessy thermal coal;

(e) Coal Valley thermal coal.

The combustion evaluations have been completed on the above coals and data evaluation and reporting is in progress.

Low Grade Coal in Utility Boilers (430702)

Expanded Use of Coal in Electrical Generation (430705) - NEP

The overall objectives of this project are to evaluate the combustion slagging and fouling properties of coals from newly opened deposits for use in power utility boilers; and to minimize emissions from conventional coal combustion through control of flame properties, chemical additives, burner design, flue gas clean up and atmospheric dispersion.

Specific objectives of the coal combustion projects are:

1. to determine the combustion and handling characteristics of each coal;
2. to evaluate the combustion performance at various feed, fineness and excess air levels;
3. to characterize the particulate and gaseous pollutants generated during combustion;
4. to assess the slagging and fouling potential of ash constituents on radiant heat transfer surfaces and superheater tubes respectively;
5. to determine the fly-ash resistivity characteristics and the ease of fly-ash collection by electrostatic precipitation; and
6. to develop combustion charts for each coal or coal blend studied.

Sage Creek Blended Thermal Coal

Under a cost-shared agreement with Techman Ltd. and Rio Algom, a three-phase project was initiated to study the combustion properties of different blends of coal from Sage Creek. In phase 1, now completed, a blend of 65% No. 4 Upper and 35% No. 4 Lower seams was burned in the pilot-scale research boiler. This oxidized coal ignited and burned with a stable flame, but burn-out was marginal and slagging of refractory surfaces around the

burner was severe. The marginal burn-out was due largely to the high percentage of oxidized vitrinite. At 5% oxygen in the flue gas, the severity of slagging was reduced and the carbon burn-out improved slightly.

The tendency of superheater tubes to foul with this coal was very low. All deposits were loose and powdery and would be easily removed by routine soot-blowing.

Sulphur dioxide emissions, which reflected the low-sulphur content of the coal, were well below the current US Environmental Protection Agency guidelines for new sources.

Nitric oxide emissions, marginally exceeded the allowable EPA guidelines, but should not be a problem with most larger boiler-burner configurations.

Improved carbon burn-out would be likely to be achieved by blending the No. 4 seams with another seam or with different coals containing higher percentages of volatile matter and reactive maceral forms.

This latter observation led to Phase II of the project in which the move reactive seam No. 2 was utilized in a blend with the No. 4 seam. The three component test blend comprised 25%, 50% and 25% of No. 2, No. 4 Upper and No. 4 Lower seams respectively and was washed to 16% and 12% ash for two combustion tests.

The major conclusions were that the addition of No. 2 seam improved the reactivity and decreased the slagging propensity. Since the fouling tendency of the original No. 4 seam blend was low it was unchanged by the addition of the low fouling No. 2 seam. The emissions of SO_2 and NO were essentially unchanged and were within the current guidelines for new sources.

Shaughnessy Thermal Coal

CCRL, in collaboration with Fording Coal Limited, conducted combustion performance trials on a sample of washed Shaughnessy coal in the CCRL pilot-scale research boiler. The coal, which was obtained from a newly-opened seam near Lethbridge, Alberta, was ranked as high volatile bituminous C and contained less than 1% sulphur and 12% ash on a dry basis.

The combustion trials on the coal were conducted in the CCRL pilot-scale boiler and confirmed chemical and petrographic analyses which showed that the coal was an acceptable boiler fuel.

The coal sample received, handled and pulverized without difficulty, ignited readily and produced stable flames at greater than 99% combustion efficiency. The coal ash produced moderate slagging of refractory-lined surfaces and superheater deposits were light and powdery with no evidence of fouling.

Sulphur dioxide emissions were borderline with respect to the current allowable North American guidelines. The nitric oxide emissions exceeded these guidelines, but in practice these emissions could no doubt be reduced through the utilization of more appropriate available burner hardware and technology.

Quintette Thermal Coal

The combustion performance of Quintette coal was evaluated in a pilot-scale, pulverized-fired research boiler in collaboration with Denison Mines Ltd. The coal, which contained 8% total moisture and about 17% ash, handled and flowed readily and burned with acceptable ignition and flame stability. The coal ash sintered on high temperature refractory-lined boiler surfaces, but deposits on superheater surfaces were light and powdery and did not constitute a fouling problem. The potential of the coal for low-temperature corrosion was minimal. Emissions of nitric oxide and sulphur dioxide were less than current allowable North American guidelines.

Blackfoot Thermal Coal

Under a collaborative agreement with Crows Nest Resources Limited CCRL carried out combustion performance evaluations to determine the feasibility of using three low rank coals from the Gleichen area of Alberta as boiler fuels. The coals were obtained from the Blackfoot deposit of the Edmonton formation east of Calgary. Two of the coals were ranked as high volatile sub-bituminous "B" and one as a lignite "B" by the Parr classification method. The two sub-bituminous coals were designated Poor Eagle and Eastern and the lignite was designated Central. The coals contained less than 0.5% sulphur; Poor Eagle contained 30% ash, Eastern 25% ash and Central 40% ash.

The major conclusions of the project were:

1. Ignition and flame stability of two sub-bituminous Blackfoot coals, Poor Eagle and Eastern were both excellent. Burn-out of char particles was excellent with combustion efficiencies in excess of 98%, when the pulverized coal grind was typical of conventional operating practice (75%-85% <75 μm). Central coal, a lignite by classification, was only marginally acceptable with a combustion efficiency of less than 94% using one third oil support. It must be noted that this coal would be expected to perform better in full scale equipment.
2. The furnace bottom deposits, although quite heavy, were of friable sintered composition with no evidence of slagging.
3. Coal beneficiation to reduce extraneous ash would significantly improve the combustion properties of these coals, particularly Central.

The fouling tendency of the coals was low to medium; pilot-scale trials confirmed that all deposits were loose and powdery and could be easily removed by normal soot blowing procedures.

Sulphur oxide emissions, which reflected the low-sulphur content of the coals, were well below the current US Environmental Protection Agency guidelines for new sources. Because of the basic nature of the coal ash, 5% to 25% of the sulphur was retained in the ash deposits.

Nitric oxide emissions for all coals exceeded slightly the currently allowable EPA guidelines. However, appropriate choice of combustion equipment for full-scale operation would allow these guidelines to be easily met.

Fly-ash resistivities during the tests were in the range 9 to 11 log ohm-cm, which is considered a reasonable range for electrostatic precipitators.

Coalspur Thermal Coal

The combustion performance of Coalspur coal was evaluated in the CCRL pulverized-coal-fired research boiler in collaboration with Denison Mines Ltd. Chemical and petrographic analyses of this coal, which indicated that it could be utilized acceptably as a thermal fuel, were confirmed by the pilot-scale combustion trials. The 13% moisture, 9.5% ash coal handled and flowed readily through the pilot-plant conveying systems.

Grinding the coal to 70% minus 75 micrometers, a typical operating pulverized coal grind, resulted in easily ignitible, stable flames. The resultant furnace bottom ash consisted primarily of a sinter-like deposit, with slight surface glazing. The superheater deposits were light and powdery, with no evidence of fouling.

The potential of Coalspur Coal for low-temperature corrosion was minimal, and sulphur dioxide emissions were well below current allowable North American guidelines. Nitric oxide emissions marginally exceeded these guidelines at an excess combustion air level of 29%, but were marginally lower than the guidelines at an excess air level of 16%.

Galt Seam Thermal Coal

Under a collaborative agreement with Petro Canada Exploration Inc., the Canadian Combustion Research Laboratory (CCRL) carried out a research project to evaluate the combustion performance of washed Galt Seam coal from the Kipp Mine, located near Lethbridge, Alberta. This coal, ranked as high volatile bituminous "C" by ASTM classification procedures, has not been previously burned in industrial-size equipment. It contains about 15% moisture, 12% ash and 0.6% sulphur.

The washed coal handled and flowed readily, had excellent ignition and flame stability and burned with combustion efficiencies in excess of 99%.

The sulphur content of this fuel is quite low and about 23% of this sulphur is neutralized during combustion by the alkaline cations in the coal ash. The measured emission rate of 0.32 kg SO_2 per GJ of fuel input, is well below the EPA 1977 guideline of 0.58 kg SO_2 per GJ for new combustion sources.

The nitric oxide emission rate of 0.43- 1 kg/GJ of fuel input, is above the maximum EPA 1977 guideline of 0.34 kg NO/GJ. In practice, however, these NO_x emissions can be reduced through utilization of modern burner system designs.

The electrical resistivity of the fly ash from both trials was in the 8 to 9 log ohm-cm range (at combustible contents below 5%), indicating that electrostatic precipitation efficiencies should be quite high. From this evidence, it is expected that good precipitator performance will be achieved in full-scale units.

The tendency of the coal ash to slag on high temperature refractory surfaces is quite evident. This is consistent with the slagging propensity predicted from the analytical data. However, the tendency for the coal ash to produce superheater fouling problems is low and should be effectively controlled by routine soot-blowing.

Magna Thermal Coal

The combustion performance of Magna coal from NE British Columbia was evaluated in the CCRL pulverized-coal-fired research boiler in a collaborative program with Gulf Canada Resources Inc. Chemical and petrographic analyses of this coal, which indicated that it could be utilized acceptably as a thermal fuel, were confirmed by the pilot-scale combustion trials. The 15% moisture coal handled and flowed readily through the pilot-plant conveying systems.

Grinding the coal to 70% minus 75 μm, a typical operating pulverized coal grind, resulted in easily ignitible, stable flames. The resultant furnace bottom ash consisted primarily of a sinter-like deposit with slight surface glazing. The superheater deposits were light and powdery with no evidence of fouling.

SO_2 emissions were well below current allowable North American guidelines, and NO emission marginally exceeded the guidelines at excess combustion air levels of 30% and 22%. The resistivity of the fly ash (about 10^8 to 10^{11} ohm-cm under typical boiler operating conditions) was in the optimal range for good electrostatic precipitation.

Other Thermal Coals Evaluated

In addition, during the year collaborative combustion evaluations were undertaken on the following thermal coals:

Balmer Coal (Harmer Seam)	B.C. Coal
Greenhills Coal	B.C. Coal
Lodgepole Coal	Crows Nest Resources Ltd.
Belcourt Coal	Denison Mines Ltd.
McCleod River	Techman Ltd.
Mercoal Coal	Techman Ltd.

The combustion experiments have been completed and data evaluation, analyses and reporting are in progress.

Flue-Gas Cleanup and Dispersion

Combustion of Suncor Coke

CCRL in collaboration with Suncor Inc. conducted a series of combustion tests to determine the effectiveness of firing limestone additions at various levels with pulverized petroleum coke to reduce SO_2 emissions. The coke contains 6% sulphur and 2.6% ash as well as 1050 ppm Vanadium and 450 ppm nickel. The following conclusions could be drawn:

1. Steam output for coke treated at a Ca/S mol ratio of 3.2/1 decreased by 25% over a 6-h period relative to untreated coke. This decrease in steam output can probably be compensated for by routine soot-blowing of furnace walls every 2 to 4 hours.
2. Bottom ash tended to slag on refractory surfaces with the most severe slagging at Ca/S mol ratios of 1.2 and 3.2. At the intermediate Ca/S mol ratios of 2 and 2.5, the slag deposits were less severe.
3. All superheater deposits with limestone-treated coke were powdery and bulky. Routine soot-blowing should suffice to keep convection surfaces clean.
4. Fly ash electrical resistivity increased with the limestone dosage rate and approached the optimal range of 10^8 to 10^{10} ohm-cm at flue gas temperatures of 350°C.
5. Fly ash loadings for coke treated at a Ca/S mol ratio of 3.2/1 were 5 times higher than for untreated coke, as might be expected.
6. Pilot-scale precipitator efficiencies decreased from 99% with untreated coke to about 96% with limestone-treated coke at a Ca/S ratio of 3.2. Limestone additions to Suncor coke did not affect NO emissions.

Plume Dispersion

In 1981, consolidation of all the plume spread data generated during the six year CANMET/industry plume dispersion research program, resulted in a paper to the 74th Annual Air Pollution Control Association Technical meeting in Philadelphia.

The plume spread parameters have been evaluated and compared to the standard predictive relationships established by Pasquill and Gifford. The data correspond to neutral and stable conditions, Stability Class C to F but excludes any limited-mixing or layered atmosphere studies or situations where topography influences plume spread. In all, ten sources in five geographic regions were studied during spring, fall and winter.

The Pasquill-Gifford curves as modified by Bowne for rural conditions represent a convenient means of comparing the data obtained under corresponding stability and topographic conditions in Canada. The variation of measured horizontal spread parameters, σ_y with downwind distance differed significantly from the P/G curves, being wider by at least two stability classes for unstable/neutral, i.e. A/B rather than C/D, and for stable C, rather than E. In the case of very stable F class, the measured σ_y values correspond to A class, six classes wider than expected. The vertical spread parameters, σ_z, were usually in agreement with P/G curves from 4 to 10 km from the source. Closer to the source, σ_z was greater and farther from the source, σ_z was less than predicted. It was also found that the bulk Richardson number could be used to classify the plume spread parameters in a similar manner to the P/G stability classes.

The consolidated data reported in the above paper has been accepted for publication in Atmospheric Environment.

Minor and Trace Element Emissions

During 1981 CANMET supported a Canadian Electrical Association contract to measure trace element emissions from two coal-fired power stations - Battle River in Alberta and Lingan in Nova Scotia. A preliminary report, prepared by Battelle-Northwest, the prime contractor has been completed.

Coal-Liquid Mixture Combustion (430706)

The effect of the escalation of oil prices and instability of offshore supply to eastern Canada, coupled with the abundance of domestic coal supplies has led to a research and development program encompassing technologies relating to the production and combustion of coal-liquid mixture fuels (CLM).

CLM technology provides a short to medium term energy source which has significant potential in reducing oil consumption at power stations, industrial steam raising and other process equipment that was originally designed for oil-firing and cannot readily be converted to alternate fuels. Energy, Mines and Resources Canada is supporting the utilization of CLM technology in Eastern Canada through National Energy Program Special Atlantic initiatives.

The Canadian CLM program embraces both demonstration-scale projects and associated technology support through R & D. The demonstration projects have included the COM firing of a 10 MW(e) utility boiler at Chatham, New Brunswick with plans for the firing of a larger unit. Also in the demonstration program were the first phases of a commercial COM preparation facility and a blast furnace tuyere CLM injection project. Research and development studies include COM preparation, properties and combustion. An important part of the program has been the application of the spherical agglomeration process to the benefication of high-ash eastern Canadian coals and its integration into CLM preparation. The feed coal for the utility demonstration project has been reduced to less than 10% ash and 4-5% sulphur from 20-25% ash and 7-8% sulphur using this process.

Chatham, N.B. Utility Boiler Demonstration

The New Brunswick Electric Power Commission and CANMET have undertaken a cooperative demonstration project to evaluate the feasibility of burning coal-oil mixtures in a small utility boiler. A paper briefly describing the three phases of the project and discussing the erosive wear of CLM burner tips and other components has been presented.

In the first phase of the project no major equipment modifications were undertaken, except the in-line addition of a system for mixing pulverized coal in No. 6 fuel oil. In the second phase, coal benefication by spherical

agglomeration was incorporated into the COM preparation to reduce environmental emissions of fly ash and sulphur dioxide and to minimize burner tip and equipment wear. This wear can be directly attributable to the abrasive coal ash in the fuel. The third phase of the project incorporated modifications to improve the performance of the agglomeration process and the reliability of CLM handling equipment. CLM's, having coal contents of up to 40% by weight, have been utilized and two different burner types, constructed of several different materials, have been examined in order to minimize the erosive wear of burner tips. It is clear that burner design and materials selection will play important roles in the development of burner components which meet acceptable performance criteria.

After completing more than 1500 hours of operation on CLM's ranging from 10 wt % to 40 wt % coal, it may be concluded that:

1. Wear damage appears to be solely due to abrasive wear and there has been no metallurgical evidence of any prior corrosion.
2. The use of harder materials, such as tungsten carbide, significantly reduces the burner tip erosion. There appears to be an inverse variation between material hardness (H_v) and wear rate (W) of the form $W/H_v n$ = constant, although it is difficult to assign exact values due to the lack of precise control of critical operating parameters. It does appear that the wear rate is higher than might be expected from the literature.
3. Pumps, valves and secondary grinding equipment also suffered from significant wear-related damage which resulted in deterioration of performance. It is felt that this problem can be eliminated by appropriate materials and equipment design considerations. Pipework was relatively unaffected by wear, essentially due to the low prevailing fluid velocities.

The major problems of burner tip erosion may be solved by choice of a less abrasive coal, improved coal cleaning by ash and pyrites reduction, further reductions in coal particle size, materials selection and the use of external-atomizing burners, utilizing low CLM efflux velocities.

Ontario Research Foundation

The major impediment to the acceptance of CLM fuels by industry in the Maritimes has been the abrasiveness of the eastern Canadian coals used in the test program, resulting in premature and unacceptable failure of nozzle components. In order to provide some quantitative data on this problem the Ontario Research Foundation and CANMET have undertaken a joint project to study the erosion behaviour of burner tips, when burning CLM made from eastern Canadian coals. Two 300 h combustion tests have been undertaken in a small 10 GJ/h boiler in which a Y jet internal-mix burner of typical design was compared with a highly turbulent externally mixed burner. Both burners were steam atomized and had been tested in previous COM evaluations, as reported by Brandstatter of Ontario Research Foundation. This program has indicated that erosion rates are more than halved in the externally-mixed burner, when compared to the Y-jet burner. In addition the test data indicated an initial period of accelerated wear for both burners, occurring within the first few hours of use. This can be attributed to a "breaking-in" of the nozzles from the polishing action of the coal and ash particles in the fuel.

General Comminution Incorporated

General Comminution Incorporated (G.C.I.), a company affiliated with the University of Toronto, Department of Chemical Engineering, has undertaken a joint project with CANMET to develop operating data and scale-up information on a small 1 t/h Szego orbital grinding mill.

The mill offers attractive advantages in size, power requirements and its ability to grind coal in oil or water to very fine sizes (mean diameter 15 μm). Since the N.R.C. spherical agglomeration process requires very fine coal to give high ash removal, the combination of the Szego mill and the NRC process in the Scotia Liquicoal project should provide much information on the commercial long-term feasibility of the mill. Having just completed the CANMET project, G.C.I. is now seeking an industrial user for its own commercial feasibility studies.

Scotia Liquicoal

The Scotia Liquicoal coal-oil emulsion preparation facility located in Dartmouth, N.S., incorporates two developing Canadian technologies. The feed coal is beneficiated, using the National Research Council (N.R.C.)

spherical agglomeration process, after being milled to about 15 μm mean diameter in a Szego mill developed by General Comminution Inc. of Toronto. The Dartmouth facility which will produce about 6 t/h of fuel was developed from scale-up data provided by a small pilot-scale facility operated by Scotia Liquicoal on the premises of the Technical University of Nova Scotia in Halifax, N.S. The project has largely been funded to date by the Canada-Nova Scotia Oil Import Substitution Agreement, administered jointly by Canada and the province to find viable alternatives to fuel oil in Nova Scotia.

At the present time, funding is being provided by the National Research Council, Atlantic Research Laboratories and CANMET to develop a burner which will resist the abrasiveness of the fuel and withstand a 1000 h combustion trial in a 20 GJ/h industrial boiler.

Centre for Energy Studies, Technical University of Nova Scotia

The Centre for Energy studies (C.E.S.) of the Technical University of Nova Scotia, is in the process of constructing a facility for the combustion testing of CLM burner hardware. This flame tunnel furnace combined with access to two small industrial boilers located near the University, will give C.E.S. and the Atlantic region a much needed combustion test facility for evaluating burner hardware and fuels.

In a collaborative project with CANMET, C.E.S. has been contracted to survey and evaluate commercially available oil-burning equipment and to assess its potential for CLM combustion. In this review, major oil burner suppliers in both the utility and industrial fields were contacted for the information available on their equipment. In addition, those manufacturers known to have experience in handling CLM's were requested to supply such information, whenever possible. The final phase of the project was a review of oil nozzle testing methods for use with CLM fuels. The final report is now available from CANMET through TID.

Atlantic Coal-Liquid Mixtures Working Group

The Atlantic CLM Working Group is a coordinating body for CLM technology developments in the Maritimes and was formed in early 1981 to review research proposals before submission to the various funding agencies. The early meetings took the form of informal information exchanges, but later the

group organized and sponsored a successful workshop on CLM combustion technology which was held in December 1981 in Halifax, N.S. The working group is comprised of interested participants from the maritime utilities, coal producers, industry, universities and other research agencies as well as CANMET and the coal branch of Energy Policy Sector of EMR. It is noteworthy that this group will provide input to the technical committee of the coal/water project being undertaken by EMR in the Maritimes.

International Energy Agency

Canada (CANMET) is a participant in the International Energy Agency (I.E.A.) Coal-oil Mixtures Implementing Agreement. This is a co-operative agreement in which the participating countries agree to technical cooperation and exchange in various annexes dealing with specific areas of CLM technology development. At the present time 5 countries have signed; Sweden, Holland, Japan, U.S.A. and Canada. The U.K. is expected to sign the agreement in the near future.

Annex 1 of the agreement is an assessment within each participating country of the potential for CLM conversions, fuel resources and of support R & D activities. Other annexes that are in the process of development deal with utility and industrial CLM demonstration, R & D base technology support and coal beneficiation/CLM preparation.

Emerging Energy Utilization Systems

The efforts of this CCRL section are directed largely at expediting the application of fluidized bed combustion technology (FBC) to the Canadian energy picture. The perceived benefits of the FBC are as follows:

1. The ability to burn high-sulphur coal with convenient control of SO_2 emissions by means of limestone injection. This is important for eastern Canadian coals.
2. The ability to burn fuels having combinations of high moisture content, high ash content and low reactivity, such as wood waste, coal washery rejects, and coke by-products from oil sands extraction.

3. An economic means of burning solid fuels cleanly in small as well as in large installations. FBC might thus provide a means for utilizing coal or wood waste to replace oil and natural gas in the commercial and industrial markets.
4. A potential means to achieve more efficient coal-to-electricity cycles, through combined cycles based on pressurized FBC.

The following summary of the section's activities in 1981 is organized to correspond with the Project Elements in force for FY 1981.

Pilot-Scale and Demonstration Fluidized Beds (430703)

Fluidized Bed Design Parameters

Objectives

Designers of full-scale FBC equipment have a continuing requirement for detailed information which can often be generated on pilot-scale equipment. To meet this need, CCRL began in 1975 to develop pilot-scale FBC research facilities, with the objective of building up a bank of performance data for various Canadian fuels and sulphur sorbents. A combustor 25 cm in diameter was operated from 1978 until mid-1980, when it was replaced by a substantially more versatile rig, with a combustor having a cross-section of 38 cm x 40 cm.

Progress in 1981

Papers and reports were published on nearly all the combustion test programs previously carried out using the 25 cm diameter combustor, specifically:

1. ERP/ERL 81-32(CF) describes a combustion evaluation program carried out on an oxidized coal from the Line Creek area of British Columbia under a cost-shared project with Crows Nest Resources Ltd. Also, a paper based on this work was presented at the Spring Technical Meeting of the Canadian Section of the Combustion Institute, held at Carleton University, May 14 and 15, 1981.

2. ERP/ERL 81-27(TR) describes a combustion evaluation program carried out with Suncor coke, as an in-house project. This was presented at the 64th Chemical Institute of Canada Conference, held in Halifax, May 31 - June 3, 1981.
3. ERP/ERL 81-30(CF) describes a combustion evaluation program carried out with Onakawana lignite from the James Bay area of Ontario. This project was cost-shared with Onakawana Development Ltd.
4. ERP/ERL 81-36(J) describes a detailed comparison of sulphur neutralization by natural ash constituents for two coals, Highvale, (Alberta sub-bituminous) and Minto (New Brunswick bituminous). This work formed the basis of an M.Sc. research thesis by N.S.H. Stover, who was on the staff at CCRL at the time. He successfully defended his thesis at the University of Western Ontario in June, 1981. An abbreviated version (ASME Paper 81-WA/Fu-5) was presented at the ASME Winter Annual Meeting in Washington, D.C., in November 1981.

Installation of the new 38 cm x 40 cm pilot-scale FBC combustor, known as the Mark II rig, was completed. This involved fitting fuel and sorbent feed systems, installing an impressive complement of measuring and recording instrumentation, developing and installing a fly ash reinjection system and access platforms, and providing ductwork for the flue gases. Two components of the complete system are not yet in service, these are an air-cooled heat exchanger and a bag filter, which will respectively cool and remove particulates from the flue gases. Their incorporation into the system awaits completion of a small fanhouse outside the pilot plant, to house the cooling air blower and the induced draft fan. In the meantime a temporary by-pass duct from the cyclone dust collector to the laboratory breeching makes it possible to operate the combustor.

Installation was followed by run-in and baseline tests in which the combustor was operated to prove the performance of the ancilliary systems, establish the time required to reach equilibrium conditions after light-up, and determine the number of bed cooling tubes required under various conditions of fuel input and bed temperature. This was done with an "easy" coal, a reactive lignite from Bienfait, Sask. After minor adjustments and modifications were made, the Mark II FBC rig performed satisfactorily in every way.

A report (ERP/ERL 81-55(TR)) describing Mark II FBC research rig has been prepared and is now at the ERL word processor. Work has since proceeded with the combustion performance evaluation programs for two coals:

1. Onakawana lignite was chosen as the fuel for the first program, partly to extend the information gained from the study previously carried out with the 25 cm combustor, and partly to calibrate the Mark II rig against its predecessor. It was found that with this high-moisture coal, some minimum fraction of coarse coal, +6 mm in size, is necessary to maintain bed temperature at the desired level. If the feedstock consists of 6 mm x 0 coal, the time required for drying is such that much of it is elutriated before combustion is complete and as a result the bed temperature drops and the freeboard combustion becomes excessive. Further trials are planned to define the minimum fraction of coarse coal which, being too heavy to elutriate, would enable the desired bed temperature to be maintained. However, these had to be postponed until more coal could be obtained, and will be carried out in 1982.
2. The fuel for the second test program was an oxidized bituminous coal from British Columbia which because of its low reactivity has been found unsuitable for conventional combustion technology, unless blended with more reactive coals. Comprehensive tests, involving a range of bed temperatures and a range of fluidizing velocities, both with and without fly ash reinjection, showed that this coal can be burned with acceptable combustion efficiency in a fluidized bed combustor, provided that bed temperatures of 900°C or more are maintained, and fly ash reinjection is employed. Test work was completed in early December and data reduction is underway.

Preparations have begun for a study on the effect of limestone size consist on sulphur capture and combustion performance. This work, which will be carried out in early 1982, is in direct support of the CFB Summerside project, which is described later.

IEA Activities

Canada participates in a 9-nation information exchange agreement on atmospheric fluidized bed combustion, sponsored by the International Energy Agency. The head of the Emerging Energy Utilization Systems section serves as the Canadian respresentative, and in that capacity attended an Executive Committee meeting in Norway. Canada's participating projects are the CFB Summerside demonstration and the in-house pilot-scale R & D program.

Fluidized Bed Mechanisms

Objectives

CCRL uses contracting-out to accomplish a significant amount of R & D, as a supplement to the in-house program, and with the same general objectives. Contracts range from short-term work with narrow, specific objectives, to long-term studies, extending over several years, with the broad objective of adding to the data base on FBC performance of Canadian fuels and sorbents. The following three contracts were carried out during 1981.

Queen's University - Fluidized Bed Combustion

This contract was initiated in 1978 as a two-year contract, and has now been extended for another two years. The first objective, to equip Queen's University with a pilot-scale combustor, essentially identical to the CCRL Mark II FBC rig, has now been accomplished, and the facility is ready for hot commissioning. The contract extension specifies an R & D program to evaluate the performance of various Canadian limestones as sulphur sorbents, and to clarify factors affecting efficiency of sorbent utilization. The work will complement the data base being built up by the CCRL in-house program.

Combustion of Syncrude Coke (A. Ahlstrom Ltd.)

The Syncrude oil sands recovery plant produces a high-sulphur, relatively unreactive coke at the rate of 2000 to 3000 tons per day. Since it is an unsuitable fuel for conventional combustion technology it is presently being stockpiled. If it could be used as a fuel for steam generation, it would eliminate the present need for natural gas at the plant and would thus have a substantial influence on the design of future tar sands plants.

A variation on conventional FBC technology, which seems well-suited to low-reactivity fuels, is the recirculating fluidized-bed combustor which has been successfully applied to industrial boilers, in sizes up to 90,000 kg/h of steam, by the Finnish firm of A. Ahlstrom Ltd. To explore a potential of this technology for burning Syncrude coke, CCRL initiated a contract under which 20 tons of coke were burned in Ahlstrom's pilot-scale combustor. Since no limestone from the Fort McMurray area was available at the time, a Swedish limestone was used as the sulphur sorbent.

The results were encouraging with a combustion efficiency ranging from 95 to 98% and a sulphur capture of 90% was achieved with a Ca/S molar ratio of about 2. Ahlstrom's final report was received in December and has been circulated to the oil sands industry. Discussions are now underway to reach concensus on what steps should be taken next.

Air/Gas Permeability of Compressed Coal Plugs

A proprietary feeder developed in Canada to feed hardwood chips into a high-pressure steam cooker appears to have potential as an improved method for feeding coal into pressurized reactors such as gasifiers and fluidized-bed combustors. Performance trials with coal in a prototype feeder have not been possible to date, due to other committments on the part of the feeder manufacturer.

However, to develop some background information, CCRL initiated a contract for a series of bench-scale tests in which coal plugs were formed under various conditions of pressure, moisture content and size consist. The permeability of these plugs to gas over a range of pressures was then measured. The work was done by McGill University, under a sub-contract from Warnock Hersey.

The final report was received in June 1981, and results show that plugs formed at pressures from 3,500 to 14,000 kPa can be impermeable at gas pressures up to 1,400 kPa. As moisture content increases, the pressure required to form an impermeable plug decreases. On this basis prototype tests stand a good chance of success, but discussions with the feeder manufacturer have not yet resulted in an acceptable proposal.

Summerside Heating Plant

Objectives

This is a demonstration project co-sponsored by EMR and DND, by which the first atmospheric FBC boilers in Canada are being installed in a heating plant addition at CFB Summerside in Prince Edward Island. The design fuels are a Cape Breton coal containing 5% sulphur and wood chips. The wood chips are a supplementary fuel, which can be co-fired with coal on a demonstration basis, at a fuel rate of up to 30% of the total heat input.

Background

The project was launched in 1977, and has progressed through three stages of competitive conceptual and detailed designs, carried out by means of parallel contracts to two teams of designers. The third stage, detailed design and firm price proposal, was completed on Jan. 5, 1981 when Foster Wheeler Ltd. and Dominion Bridge Sulzer Ltd. each submitted a tender for construction of a turnkey plant addition, complete with two FBC boilers rated at 18,000 kg/h of steam each, all fuel storage and handling equipment, and all other auxiliaries.

Progress in 1981

Bid evaluation was carried out in the subsequent weeks by a small committee of specialists from EMR, DND and DCL, chaired by the project officer from CCRL. Both bids were found to be technically acceptable, and the committee recommended proceedings with the lower bidder, Foster Wheeler Ltd. Some potential for design modifications which would reduce cost were noted, and subsequent negotiations with Foster Wheeler Ltd. resulted in their bid being reduced by about $1,000,000 to a total price of $13,135,635. A contract for construction was awarded near the end of February.

Construction of the heating plant addition is now well underway and on schedule, under the supervision of DCL. CCRL continues to be involved through the Technical Inspection Group, which monitors quality of the work and rates on the acceptability of any proposed changes. The plant is expected to be ready for commissioning in 1982. CCRL will then take the role of lead agency in extensive testwork to evaluate the performance of the FBC boilers.

A matter of concern to DND is the cost of the limestone required as a sulphur sorbent. The boiler manufacturer's SO_2 emission guarantee is based upon the use of a double-screened limestone, available from New Brunswick at a cost of $20.50/tonne. This represents an operating cost of about $100,000/year. A by-product limestone containing excessive fines is available from the same supplier at the cost of $5.50/tonne, and still another grade, having some oversize but no fines, is available at an intermediate price. The questions raised by DND are: 1) is the most expensive product, which meets the boiler manufacturer's specification, the only one which will perform satisfactorily, and 2) if so, can that size consist be more economically obtained by buying and rescreening one of the less expensive products?

In response, CCRL has initiated a research project in which all three sizes of limestone will be tests with the design coal in the Mark II pilot-scale FBC combustor. In addition to clarifying the effects of limestone size consist of sulphur capture, the test program will also investigate other concerns such as bed defluidization due to accumulation of oversize material, and the effects of additives to modify the pore structure of the limestone and thus improve the efficiency of sulphur capture. Samples of coal and limestone have already been procured and the tests will be carried out in the first few months of FY 1982.

Fluidized Bed Coal Dryers and Power Cycles

Objectives

This project element supports the application of FBC technology in industry by means of site-specific technico-economic studies carried out under contract. It also covers advisory services by CCRL to other EMR agencies, concerning potential applications of FBC. In 1981 there were three areas of significant effort which are described in the following.

Fluidized Bed Coal Dryer

As a result of an Unsolicited Proposal, received from Luscar Ltd. in 1979, CANMET co-funded the engineering design and economic analysis of a fluidized-bed combustor which would burn coal washery rejects to provide plant heating and hot gas for coal drying. The total cost of the work was about $90,000; CANMET's contribution was $35,000.

The study was completed early in 1981. The process design was subcontracted to Dorr-Oliver Canada Ltd., while Luscar Ltd. designed the balance-of-plant (building and materials handling) and carried out the economic analysis. The total cost for a system with a 250 million Btu/h input was estimated at about $22 million, which is uneconomic under Luscar's current investment guidelines, unless a federal subsidy of $8 million were provided. It was decided not to proceed with this project at the present time.

Economics of drying coal with washery rejects as fuel are highly site-specific. At Luscars Coal Valley plant, where coal-fired drying equipment is already in place, the capital cost of an FBC burning reject coal must be met from two sources; savings in clean coal, which is the present dryer fuel, and savings in propane, which is the present fuel for plant heating. In other existing plants, where the dryer fuel is natural gas, savings could be much greater. In a greenfield scenario, the FBC system could also be credited with the capital cost of alternative drying equipment. A very attractive opportunity appears to exist at the Tumbler Ridge development where rejects could be used not only to dry coal and heat the plant, but also to heat the proposed townsite, via a district heating system.

Other coal producers have also expressed interest in the concept of utilizing washery rejects via FBC technology. In order to make the results of the Luscar study generally available, CCRL has contracted a consultant to prepare a conference-type paper from the Luscar report. This should be available by the summer of 1982.

Fluidized Bed Power Cycle

In 1979 EMR's Energy Policy Sector-Coal initiated with Nova Scotia Power Commission (NSPC) a project aimed at demonstrating an atmospheric FBC boiler generating electricity from high-sulphur coal. CCRL serves Policy Sector as a technical advisor on the project.

Studies by Coal Processing Consultants identified NSPC's Point Tupper plant as the most suitable location for the demonstration. A 150 Mw FBC boiler is proposed, and could deliver steam to existing turbogenerator equipment. However, a detailed risk analysis indicated the potential for high-temperature corrosion of superheater tubes immersed in the fluidized bed as the most serious technological obstacle. It was therefore decided to sponsor a 10,000 h program of pilot-scale metallurgical testwork in an FBC, to more

reliably identify the most corrosion-resistant alloys, and thus reduce the risk factor. NSPC will provide project management, while funding will come from the Oil Substitution Agreement.

To date, no one has carried out 10,000 h corrosion tests in a fluidized bed. Two routes are available; one is to contract the work to an offshore agency, U.S. or British, which has facilities already in place; the other is to carry out the work in Canada, in which case a research facility would first have to be built. The latter route would take longer and cost more, but more expertise would accrue to Canadian industry.

Late in December 1981 the Executive Committee decided to do the work in Canada. Combustion Engineering Superheater Ltd. will design and build a 1 m^2 pilot-scale FBC at Point Tupper, N.S., NSPC will run the 10,000 h test program, and CANMET will carry out the metallurgical evaluation. Some of the world's leading corrosion experts from the U.S. and Great Britain are participating in the planning of the research program, and will assist in the subsequent evaluation of the exposed specimens. CCRL is providing advice on the design of the test combustor.

Pressurized Fluidized Bed Combustion

Although pressurized FBC is not nearly as close to commercial application as atmospheric FBC, it has a greater potential for increased fuel efficiency and reduced emissions, particularly when applied to combined power generation cycles. At present the only Canadian activity in PFBC is being carried out by BC Hydro which, with financial support from EMR, has been working toward a 70 Mw demonstration.

In August 1981 DSS received an Unsolicited Proposal from the University of British Columbia requesting funding to develop a pilot-scale PFBC research facility. A review by CCRL judged it sound and attractive, but expensive. In subsequent discussions with UBC officials CANMET encouraged them to seek additional support from industries such as BC Hydro. If this is forthcoming it will enhance the likelihood of CANMET support, and a continuing program of R & D such as that at Queen's University may result.

Sulphur Dioxide Sorbent Utilization

Objectives

The efficient use of sorbents for SO_2 in FBC is an area requiring further research. At present, Ca/S molar ratios of about 3 are required for adequate sulphur capture, and if this could be reduced to something close to stoichiometric it would substantially improve the economics of FBC operation. Also, little is known about the performance of most Canadian limestones and dolomites as sulphur sorbents. CCRL supports and directs an MSL scientist in the development of a bench-scale technique to first, compare numerous limestones in terms of this performance as sulphur sorbents, and second, study ways of optimizing sorbent performance, either by chemical or physical means.

Progress in 1981

A bench-scale apparatus has been set up, consisting of a small, externally-heated fluidized bed, together with means for fluidizing it with a stream of simulated flue gas, and analytical equipment for measuring SO_2 concentration into and out of the bed. Batch samples of various limestones are used as bed material, thus the reduction of SO_2 in the gas passed through the bed is a parameter of sorbent performance. Independent variables are SO_2 input, fluidizing velocity, bed temperature, and of course the sorbent itself, which can be varied in size consist and chemically modified as well. About 15 Canadian limestones in various size consists have already been tested. Development of a standardized test procedure is well underway, and a gas chromatograph to measure the SO_2 in the offgas has been ordered.

Coal Reactivity Parameters

Objectives

In view of the wide range of coals available in Canada, for which little or no information relative to performance in FBC systems is available, a means of rapid ranking in terms of their relative reactivity is highly desirable. To this end CCRL has undertaken a project to develop a bench-scale FBC combustor and a procedure whereby many coals can be quickly and economically evaluated with respect to their stability for use in FBC systems. This will complement the present pilot-scale data base program which provides more detailed information, but at a slower rate and at higher cost.

Progress in 1981

A literature review of previous work on measuring coal reactivity was carried out, a bench-scale apparatus on externally-heated FBC combustor, 10 cm in diameter, was designed, and analytical equipment was ordered. A tentative batch-type test procedure was developed, and some experiments were conducted on a modified apparatus, which had previously been used for coking studies. However, this apparatus proved to have inadequate heating capability to provide definitive results. The new combustor is now in the final stages of fabrication, and test work will begin in FY 1982.

RENEWABLE ENERGY TECHNOLOGY

Biomass Combustion (450100)
Residential and Industrial Technology (450101)

Residential Heating

Wood-Fired Space Heating

The use of wood to reduce demand for premium fuels in domestic heating has grown rapidly over the past five years. With major price increases for the premium fuels projected in the future, the eligibility of wood-fired appliances for rebates under the Canadian Oil Substitution Program (COSP) and the attractiveness to many people of using a potentially renewable fuel indicate that this trend to wood heating is likely to continue.

However, there is increasing concern over the emissions from wood-fired appliances, due to incomplete combustion. Carbon monoxide and hydrocarbon levels are significantly higher than those from oil or gas furnaces in good operating condition. As well, polycycle organic matter (POM) otherwise known as polycyclic organic matter (PAH), some of which are incomplete combustion products also represent a heat loss, so that efficiency can be improved by their reduction.

CCRL has been developing a technique to measure efficiency by a continuous heat loss method, while carrying out an extensive R & D program to determine the effects of design on performance, with the goal of recommending better designs to Canadian manufacturers.

Design has been found to be significant, with sidedraft combustion designs, and to a lesser extent, horizontal baffle designs, providing increased efficiency with decreased emissions.

To increase the potential uses for wood in domestic heating, a contract was let to the Canadian Standards Association to determine safe design and operating conditions for add-on wood furnaces to existing warm air oil furnaces. Until this time, there was no standard for add-ons, and as such these units were not allowed in most areas of Canada. From this work, an equipment performance standard has been developed by CSA to allow series connections with the existing furnace. At least 15 units have been approved since September 1981 and are now eligible for rebate under the COSP program.

Another appliance which is not yet eligible under COSP is the fireplace insert, for both safety and efficiency considerations. Field trials have indicated that some inserts may be less than half as efficient as free standing stoves, due to heat loss through the masonary on outside chimneys and heat loss up the stack, after burning has been completed for those units which do not have a positive chimney connection. A contract has been let with the Centre for Energy Studies (CES), to define the relative efficiency performance of an insert in a masonary fireplace with outside chimney under four conditions: (1) plain insert; (2) insert with circulating fan; (3) insert with circulating fan and outside casing insulation; and (4) insert set as free-standing stove in room. Tests are now being run and the report is due in the spring of 1982. In parallel, a safety performance standard for inserts is being developed by Underwriters' Laboratories of Canada (ULC).

Alcohol and Organic Liquids

Only a small amount of the scientific literature has seriously considered the use of alcohol fuels in stationary source combustion. On the other hand, there is a great deal of publicity and research effort being directed specifically to the use of alcohols as an automotive fuel. It is not yet clear, however, that their use in the automobile is the best way to realize fuel economy benefits. In particular, the use of methanol as a gasoline-methanol mix type of gasohol has problems of separation in the cold weather experienced in Canda, which can both decrease fuel economy and increase emissions.

Tests carried out previously by CCRL indicate that the high-speed automotive diesel has superior fuel economy, which is enhanced under winter conditions. As the trend to diesel increases, release of middle distillates will be required if the large potential fuel savings are to be realized. Since No. 2 heating fuel is essentially the same as diesel fuel in many areas, substitution of methanol for home heating oil could free-up diesel fuel, increase our automobile fleet-fuel-economy considerably, and give methanol a derivative energy efficiency.

Laboratory trials have been conducted at CCRL over the past year. Initially, a cast iron head burner was used, but control of the air and mixing with the fuel was so poor that no satisfactory flame was obtained. It was determined that the better mixing derived from using a flame retention head burner was required for satisfactory combustion of methanol in a high pressure gun-type burner.

There is an important difference from No. 2 oil firing. Excess air and stack temperature have only a marginal effect on steady state efficiency. For example, at 46 MJ/h heat input, where the highest excess air level was measured, decreasing the excess air from 47% to 11% would only increase efficiency by 2%, even if the combustion was complete. This uncommon independence of excess air is due to two factors. First, the burner runs at a low level of excess air relative to a conventional No. 2 burner. Second, and even more important, the hydrogen loss is the dominant heat loss, ranging from 1.6 to 3 times the sensible (dry flue gas) heat loss. The hydrogen loss is effectively constant at about 14%, for all runs.

Because of the low flash point of methanol, some parts of the fuel storage system may have to modified. The fuel tank should be equipped with a check valve and a flame arrestor on the vent. A convective air condenser and absorbent bed might also be added, similar to the charcoal cannisters in automobiles. Special care should also be taken with the burner controls, because of the fuel volatility.

The general conclusions from the experiments conducted with methanol to date are as follows:

1. Methanol can be burned in conventional oil furnaces using a flame retention head burner, at steady state efficiencies of about 80%.
2. Low excess air levels, below 30%, can easily be achieved with commensurate low emission levels.
3. Steady state emissions of carbon monoxide and hydrocarbons will be less than 0.15 grams and 0.03 grams per kilogram of fuel burned, respectively.
4. Carbon monoxide is the best measure of proper burner air setting.
5. Efficiency is practically unaffected by excess air, below 50% excess air, for furnace fired with methanol. The major heat loss, due to the hydrogen in the fuel, is called the hydrogen loss; it is one-and-one-half to three times the sensible heat loss, for conventional furnaces.
6. Work must continue to find a pump suitable for long-term operation with the low lubricity and high corrosion potential of methanol.
7. A condensing furnace for methanol has been described which offers the potential for seasonal efficiencies above those for similar gas-fired systems now under development. A condensing boiler fired with methanol might offer even greater advantages.

Industrial Technology

Conventional Combustion of Pulverized Wood Chips

The combustion performance of milled planner shavings has been evaluated in a pilot-scale refractory lined kiln and compared to No. 2 and No. 6 fuel oils for the purposes of fuel substitution. The project was undertaken in collaboration with Manitoba Forestry Resources Ltd. (MANFOR) and had as its objectives:

(a) To determine the minimum degree of wood fineness required to produce an industrially acceptable flame in the pilot-scale equipment;

(b) To evaluate the heat transfer characteristics of three size ranges of milled plane shavings supplied by MANFOR and a sawdust obtained locally, using No. 6 and No. 2 fuel oils as a basis for comparison; and

(c) To characterize the particulate and gaseous products generated during combustion.

The conclusions of the project were as follows:

1. Milled planner shavings can be utilized successfully to replace fuel oil in kiln-type applications. Wood particle size appears to be the controlling parameter and the application of swirl to the combustion air tends to extend the range of particle sizes which will produce an acceptable flame.
2. Acceptable flames can be produced either without swirl if the mass median diameter is less than 145 µm or with a moderate swirl setting of 2 if the mass median diameter is less than 500 µm. An acceptable flame could not be produced with coarser products even at swirl settings up to 5.
3. Combustion efficiencies were in excess of 99.7% and it is highly unlikely that the wood residue would contaminate the kiln product.
4. Carbon monoxide and sulphur oxide emissions with the fine and medium wood products were below 100 ppm and do not pose an operational or environmental problem.
5. Nitrogen oxide emissions from wood burning, at less than 100 ppm, were less than 40% of those from No. 6 fuel oil.
6. The total heat transfer using wood was better than with fuel oil providing the wood material was finely milled. The fine wood transferred about 14% and 8% more heat to the furnace cooling circuits than No. 2 fuel oil and No. 6 fuel oil respectively. On the other hand the medium and coarse milled wood provided about 4% and 10% less heat than No. 2 fuel oil and No. 6 fuel oil respectively.

Energy Consultation

As part of an on-going effort to assist the biomass energy projects, funded wholly or in part by EMR and other federal agencies, scientific advice was given on 14 R & D submissions and the scientific authority was provided for an ENFOR research project on wood refuse combustion in the pulp and paper

industry in Canada. Project management of this 3 year project, valued at $\$1.4 \times 10^6$, has been contracted to the Technical Director of the Canadian Boiler Society and the first field unit will be studied in May 1982.

CANADIAN COMBUSTION RESEARCH LABORATORY STAFF

G.K. Lee	B.Sc., M.Sc. (Queen's), P.Eng. C.Eng.	Res. Sc. (Manager)

Emerging Energy Technology

F.D. Friedrich	B.Sc. (Sask.), M.Sc. (Queen's), P.Eng.	Res. Sc. (Head)
E.J. Anthony	B.Sc., Ph.D. (Swansea), C.Chem.	Res. Sc.
D.L. Desai	B.E. (Sardar Patel), M.Eng. (Ottawa)	Engineer
I.T. Lau		Engineer
V.V. Razbin	Dipl. Eng. (Higher Mechand - Electrical Institute, Sofia, Bulgaria)	Engineer

Conventional Coal Combustion

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R.G. Fouhse	B.Sc. (Saskatchewan), P.Eng.	Engineer
D.G. Savignac	Dipl. Mech. Tech. (Algonquin), Certified Technologist	EG. ESS
B.C. Post		EG. ESS
A. Salamon		EG. ESS
A. Agnew		EG. ESS

Energy Conservation and Renewables

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R.W. Braaten	B.Eng. (Carleton), P.Eng.	Engineer
C.E. Palmer	B.Eng. (New Zealand)	Engineer
H.P. Raghunandan	Dipl. Mech. Tech. (Algonquin), Certified Technologist	EG. ESS
T.G. Sellers		EG. ESS
J.M. MacDonald	B.A. (Trent)	EG. ESS

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D.E. Barker		EG. ESS
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R. Prokopuk	B.Sc. (Alberta)	Chemist (Head)
R.K. Jeffrey		EG. ESS
F.L. Wigglesworth		Electrician

Engineering Design and Project Monitoring

S.I. Steindl	Dipl. Eng. (Budapest), M.Sc. (Queen's) P. Eng.	Engineer (Head)

Staff Changes

J.K. Wong - Transferred to Energy Conservation Section from Conventional Coal Combustion Section (Nov/81)

Appointments

A. Agnew	Technician	CCRL
C.E. Palmer	Engineer	CCRL
J.M. MacDonald	Technician	CCRL

Journal Publications, Conference Presentations and
Unpublished Seminars or Symposium Proceedings

1. Lee, G.K., Friedrich, F.D., Steindl, S.I. and Whaley, H. "A Pilot-scale Combustion Research Facility for Low Quality Fuels", Engineering Foundation International Conference on Experimental Research into Slagging and Fouling Resulting from Impurities in Combustion Gases, Henniker, NH.; July 1981.

2. Lee, G.K., Brown, T.D., Friedrich, F.D. and Whaley, H. "Canadian Low-rank Coals; Resources, Conversion and Utilization", Eleventh Biennial Lignite Symposium, Houston, TX; June 1981.

3. Whaley, H. and Lee, G.K. "Dispersion Parameters Measured During Neutral and Stable Conditions in Canada"; Air Pollution Control Assoc., Paper 81-66PI, Philadelphia, PA; June 1981.

4. Whaley, H. and Whalen, P.J. "Burner Nozzle Wear During Coal-oil Mixture Combustion"; National Association of Corrosion Engineers International Forum, Paper 94, Toronto; Apr 1981.

5. Whaley, H. "Overview of the Canadian Coal-oil Mixture Program", Third International Conference on Coal-oil Mixture Combustion, Orlando, FL.; Apr 1981.

6. Whaley, H. and Lee, G.K. "The Behaviour of Buoyant Plumes in Neutral and Stable Conditions in Canada", Accepted for Publication in Atmospheric Environment Journal, England, ERP/ERL 81-56(J).

7. Stover, N.S.H., Anthony, E.J., Desai, D.L. and Friedrich, F.D. "Combustion Performance and Sulphur Capture During Fluidized Bed Combustion of a Western Sub-bituminous Coal and an Eastern Bituminous Coal", Paper No. 81-WA/Fu-S, ASME Annual Meeting, Washington, DC; Nov 1981.

8. Anthony, E.J., Desai, D.L. and Friedrich, F.D. "Fluidized Bed Combustion of Suncor Coke", 64th Chemical Institute of Canada Conference, Halifax, Nova Scotia; June 1981.

9. Anthony, E.J., Desai, D.L. and Friedrich, F.D. "The Fluidized-bed Combustion of an Oxidized Western Canadian Bituminous Coal", Spring Technical Meeting of the Combustion Institute, Canadian Section, Ottawa, Ontario; May 1981.

10. Friedrich, F.D., Anthony, E.J., Desai, D.L., Lee, G.K. and Steindl, S.I. "Atmospheric Fluidized Bed Combustion Facilities of the Canadian Combustion Research Laboratory", Spring Technical Meeting of the Combustion Institute, Canada Section, Ottawa, Ontario; May 1981.

11. Hayden, A.C.S. and Braaten, R.W. "Domestic Oil Heating System Retrofit to Save Energy", P-DHP-9, IEA Conference of New Energy Conservation Technologies, Berlin; Apr 1981.

12. Hayden, A.C.S. and Braaten, R.W. "Oil Burner Retrofit to Save Energy and Reduce Emissions", APCA Paper 81-8.1, Annual Meeting of Air Pollution Control Association, Philadelphia; June 1981.

13. Hayden, A.C.S. "Efficient Gas-fired Heating Systems", CI/CS Paper 4-29, Spring Technical Meeting, Combustion Institute/Canadian Section, Ottawa; May 1981.

14. Hayden, A.C.S. and Braaten, R.W. "Factors Affecting Wood Stove Design and Performance", Wood Heating Alliance Seminar Proceedings, U.S. Wood Heating Alliance, Mar 1981.

15. Hayden, A.C.S. and Braaten, R.W. "Efficient Wood Stove Design and Performance", Proceedings Bioenergy R & D Seminar, Mar 1981.

16. Hayden, A.C.S., Braaten, R.W. and Palmer, C.E. "Methanol as a Domestic Heating Fuel", APCA Paper 81-8.6, Annual Meeting, Air Pollution Control Association, June 1981.

17. Hayden, A.C.S. and Braaten, R.W. "Performance of Domestic Wood-fired Appliances", Proceedings EPA Conference on Wood Combustion Environmental Assessment, New Orleans; 1981.

18. Hayden, A.C.S. "Retrofit of Domestic Gas-fired Appliances", Sixth Annual Joint ASME/APCA Information Exchange on Stationary Source Combustion, Raleigh, N.C.; Dec 1981.

19. Hayden, A.C.S. "Future Space Heating Systems", International Conference: Building to 2001, Toronto, Nov 1981.

20. Hayden, A.C.S. "Energy Conservation in Domestic Heating Systems", ASHRAE Seminar on Energy, Toronto; 1981.

21. Hayden, A.C.S. "Systémes Efficaces de Chauffage Domestique", Gouvernement de Québec, juin 1981.

22. Hayden, A.C.S. "Efficient Domestic Heating", Seminar on Behalf of EMR Policy Sector to Representatives of 11 Government Departments, Ottawa.

23. Hayden, A.C.S. "Efficiency Improvements for Domestic Heating Systems", Seminar to EMR Regional Offices, Ottawa; 1981.

24. Braaten, R.W. "Gas Technology", Solar Energy Society Conference, Winnipeg; 1981.

25. Hayden, A.C.S. "Effect of Flue Gas Temperature and Infiltration Air on Potential Corrosion in Domestic Heating Systems", Canadian Standards Association, Toronto; Apr 1981.

26. Hayden, A.C.S. "Residential Heating System", Home Restoration Seminar, Ottawa, 1981.

27. Hayden, A.C.S. "Efficient Residential Heating System", Symposium Sponsored by Society for Restoration Technology; Nov 1981.

28. Hayden, A.C.S. "Coal, its Place in Canada's Solid Fuel Heating Industry", Annual Conference of Canadian Wood Energy Institute, Toronto; June 1981.

29. Braaten, R.W. "Priority Organic Pollutants and Particulate Organic Emissions from Wood Burning Stoves", International Conference on Residential Solid Fuels, Portland; June 1981.

30. Braaten, R.W. "Domestic Wood Burning Systems", Solar Energy Society Conference", Winnipeg; 1981.

31. Braaten, R.W. "Effective Efficiency of Wood Heating Systems", International Conference on Residential Solid Fuels, Portland; June 1981.

32. Hayden, A.C.S. "Efficient Wood Stove Designs and Creosote", Annual Meeting of Canadian Chimney Sweeps Association; 1981.

33. Hayden, A.C.S. "Chauffage Efficace au Bois", Colloque de Chauffage au Bois, Gouvernement de Québec, Hull, oct 1981.

Laboratory Reports (1981)

1.	81-04(CF)	Sulphur Oxide Neutralization with Limestone During Combustion of Suncor Coke	R. Prokopuk, G.K. Lee, G.N. Banks and H. Whaley
2.	81-07(OP)	Overview of the Canadian COM Program	H. Whaley
3.	81-09(CF)	The FERA/CANMET project, Phase II; Part I: Experimental Data on the Effect of Atomization Variables on Heat Transfer from Oil Flames Using a Modified Barrel-mix Emulsion Burner	G.N. Banks, H. Whaley, R. Prokopuk, and G.K. Lee
4.	81-16(CF)	Pilot-scale Evaluation of Flame Stability and Heat Transfer Characteristics of Milled Wood Shavings	H. Whaley, R. Prokopuk, G.N. Banks and G.K. Lee
5.	81-17(CF)	Combustion Trials with Sage Creek coal Phase I - Preliminary Assessment of 65:35 Blend of No. 4 Upper and No. 4 Lower Seams in a Pilot-scale Utility Boiler	G.K. Lee, R. Prokopuk, H. Whaley and G.N. Banks
6.	81-20(TR)	Flame and Heat Transfer Characteristics of Beneficiated Tent Mountain-Vicary Creek Coal Rejects	G.N. Banks, H. Whaley, R. Prokopuk and G.K. Lee
7.	81-22(OP)	Dispersion Parameters Measured During Neutral and Stable Conditions in Canada	H. Whaley and G.K. Lee

8.	81-25(TR)	Annual Report of the Activities of the Canadian Combustion Research Laboratory	G.K. Lee, H. Whaley, F.D. Friedrich, A.C.S. Hayden and G.N. Banks
9.	81-27(TR)	Fluidized-bed Combustion of Suncor Coke	F.D. Friedrich, D.L. Desai and E.J. Anthony
10.	81-30	Pilot-scale Combustion Trials with Onakawana Lignite Phase II: Fluidized Bed Combustion	F.D. Friedrich, D.L. Desai and E.J. Anthony
11.	81-32(CF)	Pilot-scale Combustion Trials with Line Creek Coal Phase II: Fluid Bed Combustion Trials	F.D. Friedrich, D.L. Desai and E.J. Anthony
12.	81-36(J)	Combustion Performance and Sulphur Capture During Fluid Bed Combustion of a Western Sub-bituminous Coal and an Eastern Bituminous Coal	F.D. Friedrich, D.L. Desai and E.J. Anthony
13.	81-37(CF)	Combustion Trials with Shaughnessy Coal in a Pilot-scale Utility Boiler	G.N. Banks, R. Prokopuk, H. Whaley and G.K. Lee
14.	81-38(CF)	Pilot-scale Combustion Trials of Two Washed Blends of Sage Creek Coal	H. Whaley, R. Prokopuk and G.N. Banks
15.	81-46(OP)	Canadian Low-rank Coals: Conversion and Utilization	G.K. Lee, T.D. Brown, F.D. Friedrich and H. Whaley

16.	81-47(CF)	Combustion Evaluation of Quintette Coal in a Pilot-scale Utility Boiler	G.N. Banks, R. Prokopuk, H. Whaley and G.K. Lee
17.	81-48(CF)	Pilot-scale Combustion Evaluation of Three Coals From the Gleichen Area of Alberta	H. Whaley, R. Prokopuk, G.K. Lee and G.N. Banks
18.	81-52(OP) (TR)	A Pilot-scale Combustion Research Facility for Low-quality Fuels	G.K. Lee, F.D. Friedrich, S.I. Steindl and H. Whaley
19.	81-53(CF)	Combustion Evaluation of Coalspur Coal in a Pilot-scale Utility Boiler	G.N. Banks, R. Prokopuk, H. Whaley and G.K. Lee
20.	81-56(J)	The Behaviour of Buoyant Plumes in Neutral Stable Conditions in Canada	H. Whaley and G.K. Lee
21.	81-57(CF)	Combustion Evaluation of Galt Seam Coal From the Kipp Mine in a Pilot-scale Utility Boiler	G.N. Banks, R. Prokopuk, H. Whaley and G.K. Lee
22.	81-59(CF)	A combustion Evaluation of Magna Coal in a Pilot-scale Utility Boiler	H. Whaley, R. Prokopuk, G.N. Banks and G.K. Lee

Contracts and Research Agreements

Title	Contractor	Scientific Authority	Status
Recirculating FBC of Syncrude coke	A. Ahlstrom Ltd.	D.L. Desai	Completed
Coal/oil mixture combustion trials in 10 MW_e boiler Phase III	New Brunswick Electric power Commission	H. Whaley	Completed
Design and construction of Retrofit package for Gas/fired furnace	Clare Brothers Ltd.	A.C.S. Hayden	In Progress
Pilot plant studies with coal in fludized-bed	Queen's University	E.J. Anthony	In Progress
FBC coal dryer	Luscar Ltd.	F.D. Friedrich	Completed
Behaviour of coal particles under high pressure	Warnock Hersey Services Ltd.	D.L. Desai	Completed
Coal slurry preparation and testing	General Comminution Incorporated	G.N. Banks	Work Completed Awaiting final report
Coal/oil rheological characteristics	Saskatchewan Research Council	G.N. Banks	Completed
Low Btu burner development	Canadian Gas Research Institute	G.K. Lee	Phase 4 completed

NOX formation during pulverized fuel combustion	Environmental & Energy Research Laboratories Incorporated	G.K. Lee	In progress
Low-NOX burner retrofit at Nanticoke generating station	Ontario Hydro	G.K. Lee for (CEA)	Completed
Burner performance COM, Phase 1 and 2	Ontario Research Foundation	H. Whaley	Completed
Survey & evaluation of burner design for CLM combustion	Technical University of Nova Scotia	H. Whaley	Completed
Assess the use of coal/liquid fuel mixtures - Phase I	Montreal Engineering	H. Whaley	Work Completed -Awaiting final report
Technical transfer of COM combustion experience	Ontario Research Foundation	H. Whaley	In Progress
Derating assessment of utility boiler using coal/water slurry	Babcock Power Renfrew, U.K.	H. Whaley	In Progress
Prediction of slagging and fouling by lignite ash	Saskatchewan Power Corporation	H. Whaley	In Progress
Summary report on CFB Summerside	M.E.D. Taylor Consultant	F.D. Friedrich	In Progress

Preparation of a report on FBC of coal washery rejects	G. Robb Associates	F.D. Friedrich	In Progress
NO_x/SO_x emission reduction at CFB Gagetown with retrofit burners	G. Robb Associates	G.K. Lee	Completed

Representation on Technical Committees

INTERNATIONAL

British Flame Research Committee (member) ..... G.K. Lee

International Flame Research Foundation

- Aerodynamic Panel member ..... H. Whaley
- Flame Chemistry Panel (member) ..... E.J. Anthony

Organization of Economic Cooperation and Development

- Long Range Transport of Air Pollution (member) ..... H. Whaley

International Organization for Standardization (ISO)

- Domestic Oil Burners ..... A.C.S. Hayden
- Stationary Source Emissions ..... H. Whaley

International Energy Agency (IEA)

- Coal-Oil Mixture Implementing Agreemnt ..... H. Whaley
- Atmospheric Fluidized Bed Combustion Agreement ..... F.D. Friedrich

NORTH AMERICA

US/CANADA Research Committee on the Long Transport

- of Air Pollutants: Co-chaired by the US EPA AND AES
- Environment Canada (member) ..... H. Whaley

American Society of Mechanical Engineers

- Fuels Division Research Committee (member) ..... G.K. Lee
- Honors and Awards Committee (member) - Papers Review,
- Fuels Division ..... H. Whaley
- Research Committee on Corrosion and Deposits from
- Combustion Gases (member) ..... G.K. Lee
- Task force on Energy Conversion Research (member) ..... G.K. Lee
- Air Pollution Control Division (member) ..... H. Whaley

United States Department of Energy

COM Standards and Practices Committee (member) ..... H. Whaley

COM Combustion Sub-committee (chairman) ..... H. Whaley

US/Canada Interagency Wood Combustion

Research Group (member) ..... A.C.S. Hayden

Air Pollution Control Association

Residential Fuel Combustion (chairman) ..... A.C.S. Hayden

CANADA - FEDERAL

Canadian Government Specifications Board

Committee on Middle Distillate Fuels (member) ..... A.C.S. Hayden

Committee on Stationary Combustion (chairman) ..... A.C.S. Hayden

Committee on Gasoline and Alternative Automotive

Fuels (member) ..... A.C.S. Hayden

Interdepartmental

Automobile Emission Standards (member) ..... A.C.S. Hayden

Fuel Committee (member) ..... F.D. Friedrich

Retrofit Devices and Additive (member) ..... A.C.S. Hayden

Task Force on Stack Height Estimation (member) ..... H. Whaley

Future Liquid Fuel Use (member) ..... A.C.S. Hayden

Buildings R & D (member) ..... A.C.S. Hayden

Lead in Gasoline (member) ..... A.C.S. Hayden

CANADA - MISCELLANEOUS

Canadian Gas Association

Standards Committee (member) ..... G.K. Lee

Canadian Gas Research Institute (director) ..... G.K. Lee

Canadian Institute of Energy (director) ..... F.D. Friedrich

Ottawa Branch (treasurer) ..... E.J. Anthony

Canadian Standards Association

Positive Chimney Dampers (member)	A.C.S. Hayden
Air Pollution Control (member, executive)	H. Whaley
Incineration Performance (member)	F.D. Friedrich
Retrofitting of Oil Burners (member)	R.W. Braaten
Sampling Emissions and Measurements (chairman)	H. Whaley
Solid Fuel Burning Appliances (member)	A.C.S. Hayden
Solid Fuel Installation (member)	R.W. Braaten
Oil Burning Equipment (member)	A.C.S. Hayden
Energy Evaluation of Houses (member)	A.C.S. Hayden
Sub-Committee on Analytical Procedures (member)	A.C.S. Hayden
Sub-Committee on Experimental Procedures (member)	R.W. Braaten

HUDAC

Future Space Conditioning Requirements (member)	A.C.S. Hayden
Controlled Ventilation and Heat Recovery (member)	A.C.S. Hayden

ULC - CSA

Joint Committee on Wood Burning Appliances (member)	A.C.S. Hayden
Atlantic Coal-Liquid Mixture Working Group (member)	H. Whaley